

# MICROCONTROLLER HAVING A SYSTEM RESOURCE PRESCALER THEREON

## CROSS-REFERENCE TO RELATED APPLICATIONS

This application is based upon and claims the benefit  
5 of priority from the prior Japanese Patent Application No.  
2003-350380, filed on October 9, 2003, the entire contents  
of which are incorporated herein by reference.

## FIELD OF THE INVENTION

10 The present invention relates to a microcontroller  
having an arithmetic unit and internal resources having  
predetermined functions, and more particularly a  
microcontroller enabling suppression of influence to  
resource operation even when a clock frequency supplied  
15 to the arithmetic unit is increased.

## BACKGROUND OF THE INVENTION

The microcontroller has an arithmetic unit (or simply,  
CPU) and resources performing a variety of functions, and  
20 executes internal operation in synchronization with  
externally supplied clock. The resources performing a  
variety of functions exemplarily include a communication  
macro communicating with outside, and a pulse generation  
circuit generating pulses or clock signals at calculated  
25 or designated timing. The CPU controls resources by  
executing a predetermined program stored in a built-in  
memory and supplying control data to these resources. Each

resource performs operation such as communication control and pulse generation, based on the control data, etc.

FIG. 1 shows a typical configuration diagram of the conventional microcontroller. A microcontroller 1 is provided with an arithmetic unit, i.e. CPU, a memory 10 having a program storage area and a temporary recording area, and internal resources including a pulse generation circuit such as a timer 12, a communication macro 18, etc. These internal resources are interconnected through an internal bus 2. Timer 12 includes at least a bus interface 14 interfacing internal bus 2, and a counter 16 generating pulses. Timer 12 is supplied with control data, etc. from the CPU, and outputs pulse S16 to internal or external circuits at predetermined timing counted by counter 16. Communication macro 18 is exemplarily provided with at least a bus interface 20 interfacing internal bus 2, and a counter 22 generating communication clock S22, to control input/output data communication from/to the outside.

Microcontroller 1 is supplied with clock CLK externally. The CPU and bus interfaces 14, 20 operate in synchronization with the same clock CLK. Also, counters 16, 22 perform count operation in synchronization with this clock CLK. For the purpose of bus control, it is necessary for bus initiator and target units to operate with the same clock, and bus interfaces 14, 20 are so structured as to operate in synchronization with the clock.

Such a microcontroller is exemplarily disclosed in

a patent document 1 described later. This patent document 1 also discloses a method for reducing battery power consumption by decreasing an internal clock speed when a battery power voltage becomes low, with the provision of  
5 a rate multiplier/prescaler, thereby enabling a clock frequency to be variable corresponding to the battery source voltage.

As described above, in the microcontroller shown in FIG. 1, the CPU and the internal resources operate in  
10 synchronization with the externally supplied clock CLK. Here, it is required to increase a frequency of the supplied clock CLK to increase CPU processing capacity. By simply multiplying the frequency of the supplied clock CLK by N times, the CPU processing capability can be increased by  
15 N times. However, because counters 16, 22 in the internal resources 12, 18 operate in synchronization with the same supplied clock CLK, when the frequency of the supplied clock CLK is increased, control timing of the internal resources 12, 18 also becomes faster. This may impede proper control  
20 of units to be controlled by each internal resource. To avoid this, it becomes necessary to vary values to be loaded into counters 16, 22, increase the number of bits constituting the counters, etc. However, when the supplied clock CLK becomes still faster, the counter configuration  
25 in the internal resource have to be modified each time. To modify the internal resource configuration means modification of the microcontroller design, which causes

a cost increase.

FIG. 2 shows another configuration diagram of the conventional microcontroller. This microcontroller 1 is provided with a frequency divider 30 dividing the frequency of the clock CLK, by which a second clock CLK2 having a lower speed is generated. This low-speed second clock CLK2 is supplied to the internal resources 12, 18. With such a configuration, it becomes possible for the internal resources 12, 18 to operate synchronously with the clock CLK2 having the original speed, not the increased speed, even when the speed of the clock CLK is set higher in order to increase the CPU processing capability. Thus, control function with proper timing can be maintained.

In a patent document 2, as an example, a method of using the divided clock CLK as internal control clock is disclosed. In this patent document 2, there is disclosed a method of detecting a control clock speed generated by a CPU, and the clock, of which frequency is divided with a frequency division ratio corresponding to the detected speed, is supplied to an interruption control circuit, namely a resource. With such a configuration, an interruption control speed can be maintained constant, even when the CPU operation speed is increased by the increased clock speed.

[Patent document 1] The official gazette of the Japanese Unexamined Patent Publication No. 2002-202829 (published on 19th of July, 2002.)

[Patent document 2] The official gazette of the Japanese Unexamined Patent Publication No. Hei-8-249082 (published on 27th of September, 1996.)

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#### SUMMARY OF THE INVENTION

It is an object of the present invention to provide a microcontroller capable of operating an internal resource at an original speed even when a CPU clock frequency is changed.

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It is another object of the invention to provide a microcontroller having a CPU and an internal resource connected to a bus being operated at an identical frequency, while the internal resource is operated at a virtually different frequency.

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In order to achieve the above-mentioned objects, according to one aspect of the present invention, a microcontroller operating in synchronization with clock includes: an arithmetic unit operating in synchronization with the clock; an internal resource being connected to the arithmetic unit via a bus, and having at least a bus interface, and an internal circuit operating in synchronization with the clock; and a system resource prescaler which generates from the clock an operation permission signal denoting an operation permission state in  $m$  cycles out of  $n$  cycles of the clock ( $m \leq n$ ), and supplies the operation permission signal to the internal circuit of the internal resource. The above-mentioned internal

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circuit operates in synchronization with the clock when the operation permission signal denotes the operation permission state.

5 In the aforementioned aspect, preferably, the system resource prescaler includes a register storing the values m and n, and the register can be set alterably.

10 Further, the system resource prescaler includes a settable operation control register indicative of either a first operation state in which the operation permission signal is set constantly to the operation permission state, or a second operation state in which the operation permission signal is set to the operation permission state in the m cycles out of the n cycles.

15 Still further, the system resource prescaler dispersively allocates the m cycles throughout the n cycles.

20 According to the above-mentioned solution means, the internal resource is structured so as to operate in synchronization with the clock. Here, when the clock is increased in speed, an operation speed of the internal resource is controlled by the operation permission signal supplied from the prescaler. Thus, the operation speed of the internal resource can be maintained, so as to correspond to the original clock speed.

25 Further scopes and features of the present invention will become more apparent by the following description of the embodiments with the accompanied drawings.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows a typical configuration diagram of the conventional microcontroller.

5        FIG. 2 shows a configuration diagram of the other conventional microcontroller.

FIG. 3 shows a configuration diagram of the microcontroller in accordance with an embodiment of the present invention.

10       FIG. 4 shows an operation timing chart of a system resource prescaler.

FIGS. 5A shows a configuration diagram of a counter in an internal resource.

FIGS. 5B shows an operation timing chart of a counter.

15       FIG. 6 shows a configuration diagram of a system resource prescaler according to an embodiment of the present invention.

FIGS. 7A shows a diagram illustrating registers in a system resource prescaler.

20       FIGS. 7B shows a decision table in a condition decision section of a system resource prescaler.

FIG. 8 shows a modified example of a microcontroller according to an embodiment.

25       FIG. 9 shows an operation timing chart of a two-stage prescaler.

FIG. 10 shows a diagram illustrating a configuration example of a group of two-stage prescalers.

## DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The preferred embodiment of the present invention is described hereinafter referring to the charts and drawings.

5 However, it is noted that the scope of the present invention is not limited to the embodiments described below, but instead embraces all equivalents to the claims described.

With such a configuration as shown in FIG. 2, it is necessary to separate CPU bus 2 connected to the CPU from  
10 a second bus 4 connected to the internal resources 12, 18. To enable this, it is necessary to provide a bus bridge 32 between the high-speed CPU bus 2 and the low-speed second bus 4, so as to absorb the difference of the operation frequencies between buses 2, 4. However, addition of such  
15 a bus bridge brings about a cost increase. Further, in general, frequency divider 30 generates the clock CLK2 having a cycle of a multiplication by a power of 2. When the internal clock CLK2 has a cycle of an integer multiplication of the cycle of the clock CLK, the edge timing  
20 of both clocks may possibly coincide, and therefore a timing match circuit in the bus bridge can be configured comparatively easily. In contrast, when a cycle having other than the multiplication of the power of 2 or other than the integer multiplication is required, the  
25 configuration of the frequency divider shown in FIG. 2 becomes complicated. In addition, when a cycle having other than the integer multiplication is required, the bus bridge



configuration becomes complicated.

FIG. 3 shows a configuration diagram of a microcontroller according to an embodiment of the present invention. This microcontroller 1 includes a CPU, a memory 10, internal resources 12, 18, which are interconnected through an internal bus 2 in a similar manner to the conventional example. The internal resources exemplarily include a communication macro 18 and a pulse generation circuit (timer) 12. Clock CLK is supplied externally to microcontroller 1. This clock CLK is supplied to the CPU to control an operation speed and processing capability of the CPU. The clock CLK is also supplied to the resources, pulse generation circuit 12 and communication macro 18, of which interfaces 14, 20 perform bus management together with the CPU and memory 10 in synchronization with the clock CLK. Counters 16, 22 perform predetermined count operation also in synchronization with the clock CLK.

Therefore, when the frequency of the externally supplied clock CLK is increased, CPU processing speed is increased. In this case, the internal resources 12, 18 connected to the common internal bus can perform data transmission/reception to/from the CPU and the memory, through bus control synchronized with the clock CLK. Meanwhile, counters 16, 22, which are internal circuits in the internal resources 12, 18, operate in synchronization with the clock CLK. Therefore, with the frequency of the clock CLK being changed, undesirable

change of the operation speed occurs in each counter. In order to avoid the above problem, a system resource prescaler 40 is provided according to the embodiment of the present invention. System resource prescaler 40 provides an operation permission signal ENCNT to counters 16, 22, so as to control each operation time period of counters 16, 22. Counters 16, 22 perform the count operation in synchronization with the clock CLK only during the operation permission signal ENCNT denoting an operation permission state. With this control of the operation time period, even though the frequency of the clock CLK is increased, the operation speed of counters 16, 22 in the resource is maintained in the same condition as performed at the clock frequency not increased. System resource prescaler 40 is connected to the CPU via internal bus 2, and configured to have a built-in register in which timing information for generating the operation permission signal is settable, as described later. Based on the timing information set in this register, the system resource prescaler 40 generates the operation permission signal ENCNT in synchronization with the clock CLK.

FIG. 4 shows an operation timing chart of the system resource prescaler. The system resource prescaler 40 generates the operation permission signal ENCNT indicative of an operation permission state in  $m$  cycles out of 8 ( $n$ ) cycles (0 - 7) of the clock CLK. The  $m$  cycles of the operation permission state are allocated with intervals throughout

the  $n$  cycles in a dispersed manner to the maximum extent. With such dispersion, the counter can be operated at a nearly constant speed, as nearly as possible. Namely, the system resource prescaler 40 generates the operation permission  
5 signal ENCNT having a lower speed than the clock CLK, and controls the internal circuit of the internal resource to operate at a lower speed.

In FIG. 4, in case of setting values  $n = 8$  and  $m = 1$  as shown in (1), the operation permission signal ENCNT  
10 is set to the H level only in the cycles when the count value of the clock CLK is 0, in which the H level denotes the operation permission state. Accordingly, counters 16, 22 perform the count operation at a speed of  $1/8$  of the clock CLK.

15 In the case of (2) in FIG. 4, where setting values are  $n = 8$  and  $m = 7$ , the operation permission signal ENCNT is set to the H level denoting the operation permission state in seven (7) cycles, namely when the count values of the clock CLK are 0 to 6. On the other hand, the operation  
20 permission signal ENCNT is set to the L level, denoting the non-permission state, in one cycle when the count value of the clock CLK is 7. Accordingly, the counters perform the count operation at a speed of  $7/8$  of the clock CLK.

25 In the case of (3) in FIG. 4, where setting values are  $n = 8$  and  $m = 3$ , the operation permission signal ENCNT is set to the H level, indicative of the operation permission state, in three (3) cycles when the count values of the

clock CLK are 0, 2 and 5. Accordingly, the counters perform the count operation at a speed of  $3/8$  of the clock CLK. More specifically, the operation permission signal denotes the operation permission state in the 3 cycles out of the 8 cycles of the clock CLK. The operation permission states are dispersively distributed, so as to produce the operation timing as uniformly as possible. With this, the counter operation speed is controlled to obtain constant operation to the maximum extent. In the case of (4) in FIG. 4, the operation permission signal ENCNT is constantly set to the H level. Therefore, the counters perform the count operation synchronously with, and at the same speed as, the clock CLK.

As such, in the microcontroller according to the embodiment of the present invention, the operation states denoted by the operation permission signals are set in a register of prescaler 40 correspondingly to the frequency of the clock CLK. The operation permission signal ENCNT generated correspondingly to the setting information in the register is supplied to the counters 16, 22, namely the internal circuits of the internal resource. The counters 16, 22, perform the count operation in synchronization with the clock CLK only in the cycles in which the operation permission signal ENCNT denotes the operation permission state. Therefore, the counter configuration is designed so that the counter 16, 22, performs the count operation in synchronization with the

clock CLK in any case, and the count operation is controlled to be effective only when the operation permission signal ENCNT denotes the operation permission state. In this manner, the operation speed of the counter 16, 22, is  
5 variably controlled, independently of the clock CLK, by the system resource prescaler 40.

FIGS. 5A, 5B show a configuration diagram of the counter provided in the resource, and an operation timing chart of this counter, respectively. Counters 16, 22 are  
10 structured of a four-bit counter, having four flip-flops 42 and an increment circuit 44. The four flip-flops 42 has a data input terminal D and a data output terminal Q, latches the data input D synchronously with a rise edge of the clock CLK, and clears the latch condition in response to a rise  
15 edge of a reset signal RST. Also each flip-flop 42 provides an enable terminal EN, so as to perform latch operation in synchronization with the clock only when the operation permission signal ENCNT denotes the operation permission state (H level). Also, increment circuit 44 increments a  
20 supplied four-bit data by one, and outputs the incremented data. This output is feedbacked and input to the four flip-flops 42. Accordingly, during the operation permission signal ENCNT denoting the operation permission state, each flip-flop 42 latches the incremented data in  
25 synchronization with the clock CLK. This count value Cout is supplied to, for example, a pulse output section 46. This pulse output section 46 outputs pulses, or clock

signals S16, S22 when the count value Cout has a predetermined value.

In FIG. 5B, there are shown counter outputs in two states. In a state (I),  $n = 8$ ,  $m = 3$  are set in the prescaler 40, and the operation permission signal ENCNT becomes the H level in the cycles when the counter values of the clock CLK are 0, 2 and 5. During these operation permission states, each flip-flop 42 latches the input data in synchronization with the clock CLK. With this latch, the increment circuit 44 increments the counter value by one. Accordingly, the counter output Cout is incremented only three times during the 8 cycles of the clock CLK, and thus the counter virtually performs the count operation at a period of  $3/8$  of the clock CLK. On the other hand, in the case of a state (II), the operation permission signal ENCNT is constantly set to the operation permission state. Accordingly, the counter is counted up synchronously with the clock CLK. Therefore, the counter output Cout is counted up 8 times during the 8 cycles of the clock CLK.

FIG. 6 shows a configuration diagram of the system resource prescaler according to the embodiment of the present invention. The system resource prescaler 40 includes a counter 50. This counter 50 is a reloading type down-counter. A value  $n$ , which is set in a denominator setting register 60, is loaded as reloading value, and this reloading value  $n$  is counted down in synchronization with the clock CLK. To enable this function, counter 50 is

exemplarily provided with four flip-flops 52, a decrement circuit 54, a multiplexer control circuit 56 which switches a multiplexer 58 to the denominator setting register 60 side when the output Q of the flip-flops becomes zero. With  
5 such a configuration, when the count value becomes zero, the value n stored in denominator setting register 60 is loaded onto flip-flops 52, and thereafter the counter is counted down in synchronization with the clock CLK. The value n is reloaded each time the counter value becomes  
10 zero. In such a way, counter 50 counts the cycles of the value n stored in the denominator setting register 60.

Now, a condition decision circuit 66 outputs the H level only for one cycle when the counter becomes a predetermined value, based on both the value n being set  
15 in denominator setting register 60 and a value m being set in a numerator setting register 62. An AND gate 68 passes the output of condition decision circuit 66 when the operation permission signal ENCNTI supplied from a preceding stage has the H level, and feeds this output to  
20 the data terminal D of a flip-flop 70. Meanwhile, while the operation permission signal ENCNTI supplied from the preceding stage stays in the L level, the data terminal D is maintained in the L level. Accordingly, flip-flop 70 latches the data input D in synchronization with the clock  
25 CLK, and outputs the operation permission signal ENCNT via an OR gate 72. In system resource prescaler 40 shown in FIG. 6, when the system resource prescaler 40 is used as

either an independent prescaler or a first-stage prescaler, the above-mentioned operation permission signal ENCNTI supplied from the preceding stage is constantly fixed to the H level.

5        FIGS. 7A, 7B show a diagram illustrating a register, and a decision table in a condition decision section of the prescaler, respectively. Denominator setting register 60 and numerator setting register 62 shown in FIG. 7A are incorporated in an 8-bit register. A denominator is set  
10 in bits 0 - 3, while a numerator is set in bits 4 - 7. Practically, a value 'n - 1' is set for a denominator n, and a value 'm - 1' is set in the register for a numerator m, respectively. Further, in an operation control register 64, a control value is set into #0 bit, which is referred  
15 to as Run bit. When the Run bit has a value '0', prescaler operation is suspended, and rewriting into the denominator/numerator setting registers 60, 62 becomes permitted. On the other hand, when the Run bit has a value '1', the prescaler operation is activated, and rewriting  
20 into the denominator/numerator setting registers 60, 62 becomes inhibited.

Referring back to FIG. 6, when the Run bit of operation control register 64 is '1', OR gate 72 passes the output Q of the flip-flop 70, and an operation permission signal  
25 ENCNT is output. When the Run bit of operation control register 64 is '0', the operation permission signal ENCNT is forcibly set to the H level. Namely, when '0' denoting



the operation suspension is set to operation control register 64, the output operation permission signal ENCNT is constantly set to the H level, and accordingly the counter 16, 22, provided in the internal resource is constantly operated in synchronization with the clock CLK. On the other hand, when '1' denoting the operation state is set to operation control register 64, a pulse output from condition decision circuit 66 is output as operation permission signal ENCNT.

10 In order to control the operation of counter 50, an enable controller 74 is provided. When the Run bit of operation control register 64 is '0' denoting the operation suspension, an enable terminal EN of flip-flop 52 is set to the L level, and the operation of counter 50 is suspended. 15 Meanwhile, when the Run bit of operation control register 64 is '1' denoting operation state, only in case the operation permission signal ENCNTI supplied from the preceding stage is in the H level, the enable terminal EN of flip-flop 52 is set to the H level, and accordingly, 20 counter 50 performs the count operation. In other words, the counter operation is controlled corresponding to the operation permission signal ENCNTI supplied from the preceding stage.

FIG. 7B shows a decision table in the condition decision circuit. The columns show register values of the denominator  $n - 1$ , while the rows show register values of the numerator  $m - 1$ . In each cell, a counter value enabling

the operation permission signal ENCNT to set to the H level is stored. For example, in the case of  $n = 8$  and  $m = 3$ , at the time of the counter values 0, 2 and 5 stored in the cell in column #7 and row #2, condition decision circuit 5 66 outputs a pulse, so that the operation permission signal ENCNT becomes the H level. Thus, use of the decision table enables optimal setting of the dispersion condition of the operation permission state. Further, in this example of the decision table, when the denominator  $n$  is set to '1', 10 the H level denoting the operation permission state is constantly output as operation permission signal ENCNT.

FIG. 8 shows a diagram illustrating a modified example of a microcontroller according to the embodiment. In this example, the system resource prescaler is structured of 15 two-stage system resource prescalers 40A, 40B. Prescaler 40A in the preceding stage generates an operation permission signal ENCNT1 according to the values  $n$  and  $m$  being set in a built-in register, and supplies this signal ENCNT1 to prescaler 40B in the succeeding stage as operation 20 permission signal. Prescaler 40B in the succeeding stage is operated only when the operation permission signal ENCNT1 supplied from the preceding stage denotes the operation permission state. Prescaler 40B then generates an operation permission signal ENCNT2 according to the 25 values  $n$  and  $m$  being set in a built-in register, and supplies the signal to counter 16 in the internal resource 12. By configuring the multi-stage prescaler, the operation speed

of counter 16, which is an internal circuit of the internal resource, can be controlled with higher precision.

FIG. 9 shows an operation timing chart of the two-stage prescaler. In this example,  $n = 8$  and  $m = 3$  are set in the prescaler 40A of the preceding stage, and  $n = 2$  and  $m = 1$  are set in the prescaler 40B of the succeeding stage. Therefore, the operation permission signal ENCNT1 of the preceding stage becomes the H level in 3 cycles out of the 8 cycles. The operation permission signal ENCNT2 produced by the prescaler 40B in the succeeding stage becomes the H level in three cycles out of the sixteen cycles. Namely, counter 16 controlled by the operation permission signal ENCNT2 of the succeeding stage 40B is controlled at the speed of  $3/16$  of the clock CLK. In such a way, by forming a multi-stage prescaler, speed control becomes enabled with higher precision. In addition, by forming the multi-stage prescaler, it becomes easier to control different speeds on a resource-by resource basis.

FIG. 10 shows a diagram illustrating a configuration example of a group of two-stage prescalers. In this example, different operation permission signals ENCNT2-1 to ENCNT2-4 are supplied to four resources RS1 to RS4 to be controlled. For this purpose, a prescaler A provided in the preceding stage generates operation permission signal ENCNT1 corresponding to the values  $n, m$  set in the built-in register of the prescaler A. Four prescalers B provided in the succeeding stage generates operation permission

signals ENCNT2-1 to ENCNT2-4 corresponding to the values  
n, m independently set in the respective built-in registers  
of the prescalers B. The input operation permission signal  
ENCNTI being input to the first prescaler A is fixed to  
5 the H level, by which the first prescaler A is constantly  
set in operation condition.

When forming such a structure, desirably the operation  
control registers in the succeeding-stage prescalers B-1  
to B-4 can be set to any one of the following three states:  
10 an operation state; an operation suspension state; and a  
state not using the operation permission signal supplied  
from the preceding stage. For example, the prescalers B-1,  
B-2 are set so as to operate only when the operation  
permission signal ENCNT1 of the preceding stage has the  
15 H level. As a result, these prescalers B-1, B-2 are affected  
by the operation speed control by the preceding-stage  
prescaler A. Namely, the operation of the prescalers B-1,  
B-2 becomes as shown in FIG. 9. Meanwhile, the prescaler  
B-3 is set to a state 'not using the operation permission  
20 signal supplied from the preceding stage'. As a result,  
this prescaler B-3 generates the operation permission  
signal ENCNT2-3 at the timing depending on only the setting  
values n and m being set in its built-in register. Further,  
the prescaler B-4 is set to the operation suspension state,  
25 and the operation permission signal ENCNT2-4 to be supplied  
to the resource RS4 is constantly set to the operation  
permission state. As a result, only the resource RS4

operates at the highest speed in synchronization with the clock CLK.

As shown in FIG. 10, the prescaler is formed of a multi-stage configuration, and each operation control register provided in the succeeding-stage prescaler B has three alterable states, namely the operation state; the operation suspension state; and the state not using the operation permission signal supplied from the preceding stage. With the structure described above, it becomes possible to control a variety of operation speeds against the plurality of resources. In other words, even the prescalers in the microcontroller have fixed hardware configurations, operation speeds of the internal resources as controlled objects can be changed flexibly by changing the settings of the built-in operation control registers provided in the prescalers.

In the above description of the embodiments of the present invention, the counter is taken as an example of the internal circuit in the internal resource. However, the internal circuit includes, for example, a frequency divider, and other circuits. In addition, another example of the internal resource includes a control clock generation circuit for the control of a display panel, etc.

The foregoing description of the embodiments is not intended to limit the invention to the particular details of the examples illustrated. Any suitable modification and equivalents may be resorted to the scope of the invention.

All features and advantages of the invention which fall within the scope of the invention are covered by the appended claims.